Fish Passage Through Poplar Grove Creek Culvert, Alaska

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ABSTRACT

An experimental procedure was developed to analyze the ability of a highway culvert to pass fish. By using a visual technique, the swimming performance of Arctic grayling (Thymallus arcticus) was monitored in Poplar Grove Creek, Alaska. The highway culvert is 110 ft long and 5 ft in diameter, and is inadequate for fish passage if the Alaska Department of Fish and Game criteria are applied. The drainage area experienced a 20-year flood (Q_{20}) during spring 1985. Excessive pipe velocities prevented the fish from passing the culvert for 8 days. A large portion of the fish in the downstream scour pool were removed by sport fishermen during the period of high flow. Approximately 78 percent of the fish attempting to swim through the culvert were successful when the outlet velocity dropped to 7.3 ft/sec (fps) and about 95 percent swam through when the velocity receded to 6.9 fps. A request for information on fish passage was sent to U.S. and Canadian highway departments and fishery agencies. Forty-four states and all Canadian provinces responded. Twenty states reported that they generally do not have problems with fish passage through highway culverts. Eighteen highway departments reported having a good working relationship with resource agencies when addressing fish passage problems. These 18 states commonly suggested that (a) early coordination should occur between highway and resource agencies during the design phase, (b) culvert inverts should be depressed approximately 1 to 2 ft below the natural stream bed, (c) culverts having slopes greater than 1 percent should have a baffling system, and (d) the remaining culvert volume should be able to handle approximately a Q_{50} discharge.

Fish populations are widely distributed throughout Alaska and must often pass through highway stream crossings. These crossings can be crucial to the seasonal migration of fish populations because modifications to the natural stream flow conditions may impede access to feeding, spawning, or overwintering habitats. The proper design of highway culverts is essential to facilitate the passage of fish. Design criteria for culverts should be well defined to ensure fish passage but should still consider the hydrological conditions of the stream site, difficulty of installation, and economics of design and construction.

The Alaska Department of Transportation and Public Facilities (DOT&PF) is the primary agency responsible for design and construction of roads in Alaska. The Alaska Department of Fish and Game (ADF&G) has enforcement authority, as provided by the Alaska Legislature, to ensure efficient fish passage through highway stream crossings (A.S. 16.05.840 and 870). Many road projects are federally funded and require compliance with the National Environmental Policy Act (NEPA). For these cases, the U.S. Fish and Wildlife Service coordinates with ADF&G to maintain fish passage.

In order to facilitate fish passage, the ADF&G has set maximum water velocities for varying culvert lengths that can be attained during a mean annual flood discharge ($Q_{2.33}$) (Figure 1). These criteria were derived from a study performed by MacPhee and Watts in 1976 (1). They analyzed the swimming performance of Arctic grayling through various outlet velocities and 2-ft diameter culvert lengths during controlled conditions. No additional studies have been conducted that investigated the applicability of the extrapolated criteria in natural conditions or using culverts of larger diameter.

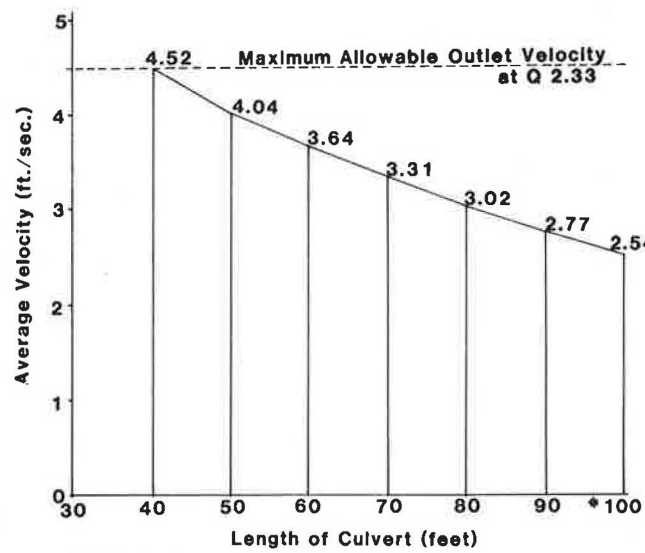

FIGURE 1 Alaska Department of Fish and Game fish passage criteria.

To meet these strict fish passage requirements, the Alaska DOT&PF must often design and install expensive drainage structures such as large-diameter culverts or bridges. Even after these structures have been provided, their general effectiveness for

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fish passage is greatly debated. Often hydrological factors inhibit designing structures that will meet the fish passage requirements. As a result, some engineers believe that ADF&G's requirements are too restrictive and add an unjustified expense to highway projects.

The Alaska DOT&PF and the University of Alaska, Fairbanks initiated a study in 1985 to investigate a highway culvert that is inadequate for fish passage according to the ADF&G criteria, yet a significant number of fish pass through it. The project evaluated the swimming performance of Arctic grayling (Thymallus arcticus) attempting to swim through the culvert.

The objectives of the study were to

1. Develop a procedure for analyzing a culvert's ability to pass fish;
2. Determine the success rate of Arctic grayling passing through a highway culvert that is inadequate for fish passage according to ADF&G criteria;
3. Determine if additional, more comprehensive studies need to be conducted to verify or modify ADF&G's criteria; and
4. Investigate the steps that other state highway departments and resource agencies are taking to address fish passage problems.

METHODOLOGY

This study took place along Poplar Grove Creek near Glennallen, Alaska. The creek's width varies from 5 to 15 ft along its 5-mi length. It flows through a culvert on the Richardson Highway at Milepost 138.1 and then discharges into the Gulkana River, which is about 1.8 mi below the crossing.

Poplar Grove Creek was selected for this project because of previous studies conducted by MacPhee and Watts (1) and Tack and Fisher (2). They compiled extensive information on the stream's fisheries and hydrology. The highway culvert at this stream crossing is inadequate according to the ADF&G criteria. Nevertheless, many Arctic grayling pass through it during the upstream spawning migration following spring breakup (personal communication, Williams and Potterville, Alaska Department of Fish and Game).

The Poplar Grove Creek culvert is 110 ft long (skewed to the road crossing at about 45 degrees), 5 ft in diameter, and is constructed of corrugated metal. It has been in place since 1953. The outlet is perched approximately 1 ft above the streambed. In the middle of the culvert, subsiding road material and traffic load have depressed the top of the pipe (Figure 2). The culvert is positioned on about a 0.5 percent slope, and no streambed material is present along the culvert's bottom. A 60- by 120-ft scour pool exists at the culvert outlet. The pool depth ranges from about 2 to 5 ft and is a popular fishing spot for local residents. The ADG&G fish passage criteria requires a maximum average outlet velocity of 1.8 ft/sec (fps) during a $Q_{2.33}$ for this culvert (Figure 1). According to ADF&G, this maximum outlet velocity will ensure that at 2.8°C, 75 percent of 9.5-in. fish will successfully negotiate the culvert.

This project included the capturing of Arctic grayling downstream of the culvert, tagging the fish according to length, and observing the grayling swimming through the culvert at various water velocities and water quality parameters. A creel census was performed at the scour pool. In addition, an inquiry for fish passage information was sent to American and Canadian highway departments and resource agencies. Arctic grayling were captured near the mouth of Poplar Grove Creek at the beginning of their spawning migration between May 20 and 22, 1985.

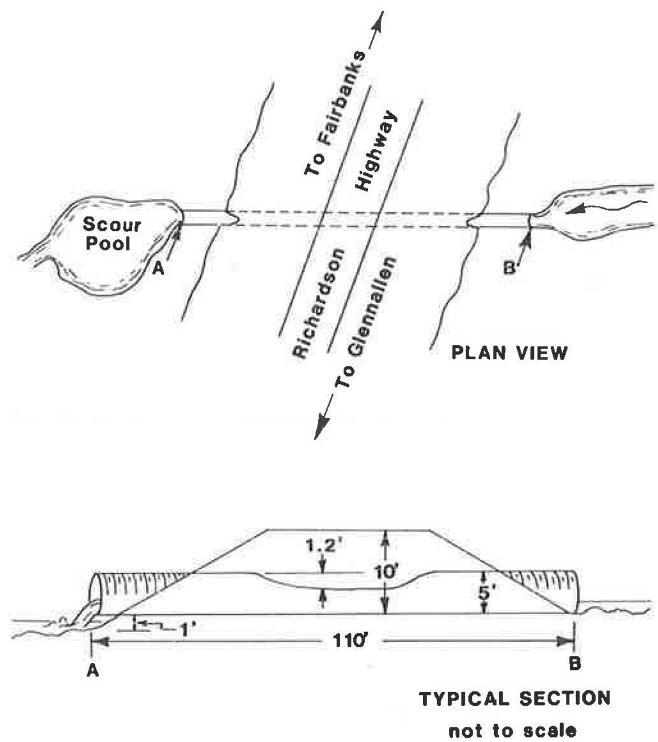

FIGURE 2 Plan view and typical section Poplar Grove Creek.

Fish were captured by dip netting. Previous studies estimated a total migrating population of about 5,000 fish. Fish were netted between 10:00 a.m. and 6:00 p.m. and immediately transferred to holding pens in a side channel of the creek. The holding pens were two 30-gal trash cans perforated with 3/8-in. holes. These "live boxes" were weighted to the stream bottom with rocks and sandbags, and only a few fish were maintained in the pens so as to minimize mortality.

Fish were individually transferred from the pens, using wool gloves, to a measuring cradle that consisted of a 2-ft plywood box lined with foam rubber and a measuring stick along its bottom. Fork length was quickly measured to the nearest quarter of an inch. The fish were then tagged through the base of the dorsal fin and released. To prevent the downstream movement of tagged fish, a temporary weir was constructed from sandbags and wire mesh, approximately 20 ft downstream of the sampling area.

The tags for this study were three 3/4-in. plastic streamers approximately 1/8 in. wide (Floy Tag and Manufacturing, Inc., Model FTSL-73). Although originally designed for use on shrimp, the tag was selected because of its configuration and light weight. It was believed to be suitable for use in this study. Tags were colored to differentiate group sizes: orange, 6 to 9 in.; yellow and blue, greater than 9 in. Tag colors were selected to enhance visibility in colored, turbid water.

Fish smaller than 6 in. were not tagged because their swimming abilities were hampered in swift water. The tag was inserted into the base of the dorsal fin via a needle that detached from the tag once it was in place. Instructions were imprinted onto the tag requesting anglers to return the recovered tags to the Glennallen Sport Fish Division. Because of the substantial distance between the tagging area and the culvert (1.8 mi), it was assumed that the fish had recovered adequately from handling and tagging to become acclimated to swimming with the tag before reaching the highway crossing. Observations of grayling attempting to swim through the culvert were facilitated by using "flashboards" positioned on the stream bottom at the inlet and outlet of the culvert. The flashboards were 8 by 4 ft and were constructed from 5/8-in., all-weather plywood that was painted light grey. Fish swimming over the boards into and out of the culvert were more easily observed against the light background.

Fish were counted as they swam over the flashboard into the culvert. Fish that swam into the culvert were recorded as attempts. Fish that swam back out of the culvert were recorded as failures. Counts were made from 2:00 to 8:00 p.m. from May 31 to June 1.

Individual-tagged fish entering the culvert were recorded swimming through the pipe by observers located at each end of the pipe via two-way radios and a stop watch. This procedure permitted timing of the fish as they negotiated the culvert.

Water quality parameters were monitored daily from the scour pool. Dissolved oxygen and apparent color were determined with a Hach DR=EL/4 water testing kit. Turbidity was monitored with a Hach Model 16800 portable turbidity kit. Temperature in degrees Celsius was measured using a pocket thermometer.

A stream gauge was installed about 20 ft upstream of the inlet and was read daily. Water velocity profiles were taken at least once daily, depending on the fluctuating water levels on the stream gauge at the culvert outlet. Velocities were measured with a Gurley meter attached to a wading rod. Poplar Grove Creek's hydrograph was calculated using Lamke's linear regression method (3).

A creel census was performed by the investigating team to determine the number of fish removed from the scour pool by local fishermen. Anglers were given an information pamphlet that explained the project and requested their cooperation.

Highway department and natural resource agencies from the United States and Canada were contacted to determine how they address fish passage problems. Their methods and approaches were then summarized.

RESULTS

Arctic grayling began entering the mouth of Poplar Grove Creek on May 20 when the water temperature had risen to approximately 1°C. Table 1 gives daily totals of fish that were tagged. A total of 1,252 fish were tagged during the 3 days of sampling. The migration began with grayling generally larger than 9 in. and was followed gradually by smaller fish. The daily migration peaked about 4:00 p.m.

TABLE 1 Daily Tagged Fish

Date	Blue >9 in.	Yellow >9 in.	Orange 9 in. > x > 6 in.	Daily
5/20/85	140	0	51	191
5/21/85	283	0	115	398
5/22/85	75	293	294	662
Total	498	293	460	1,251

Figure 3 shows the daily discharge rates through the culvert. The flow peaked at 139.1 ft^3/sec (cfs) on May 21. Grayling first were observed at the highway culvert on May 23 but were held in the scour pool for 8 days because of excessive culvert outlet velocities. Fish arrival at the culvert corresponded to the decreasing side of the hydrograph.

Figure 4 shows the calculated magnitude and frequency of peak discharges for Poplar Grove Creek. By comparing the peak discharge that occurred during the study period with the graph, 139.1 cfs should occur about every 20 years (Q_{20}). Therefore, the study took place during an unusually high peak discharge.

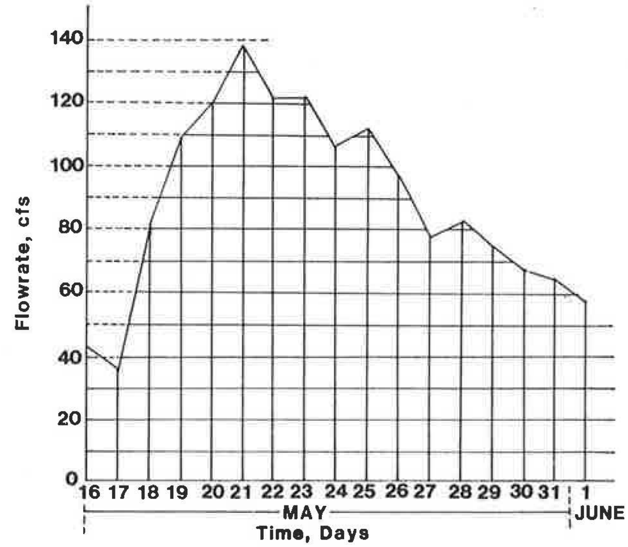

FIGURE 3 Daily discharge rates for 1985 (cfs).

Figure 5 shows the water quality in the scour pool during the study. The maximum daily water temperatures ranged from 6.6°C to 12.0°C, and apparent color fluctuated from 40 to 320 units. Turbidity ranged from 3.1 Nephelometric Turbidity Units (NTU) to 32 NTU. Dissolved oxygen varied from 9.0 mg/l to 11.2 mg/l.

Daily average culvert outlet velocities ranged from 6.9 to 10.3 fps (Figure 6). At 1:35 p.m. on May 26, one ± 9-in. grayling was observed exiting the upstream end of the culvert. The water temperature was approximately 10.3°C, and the outlet velocity was 9.2 fps. Because of abnormally high flows, the investigating crew was unable to determine how many fish negotiated the culvert during these high-flow and high-velocity conditions.

Two fish with yellow tags were observed swimming above the culvert inlet on May 27 at 5:20 p.m. The water temperature was approximately 12.0°C, and the average outlet velocity was 8.4 fps. One of the fish approximately 15 in. long was caught with fly fishing gear. At 10:00 p.m., three 16- to 19-in. longnose suckers (Catostomus catostomus) were observed swimming upstream of the culvert.

At approximately 3:20 p.m. on May 31, the first significant number of fish began migrating through the culvert. Eighty-two attempts were recorded with only 18 failures. This represents a 78 percent success rate. The water temperature was approximately 7.7°C, and the average outlet velocity was about 7.3 fps. No tagged fish were observed swimming through the culvert. All the fish whose attempts were successful were observed swimming very close to the bottom of the culvert.

On June 1, the fish began migrating about 4:00 p.m. Some 1,090 attempts were counted with 52 failures. This was a 95 percent success rate. The water temperature was approximately 9.5°C, and the average outlet velocity was 6.9 fps. Again, successful fish were observed swimming at the bottom of the culvert. Table 2 gives the time required by tagged fish to swim through the culvert. Larger fish took an average of 20.2 min to swim through the culvert, whereas

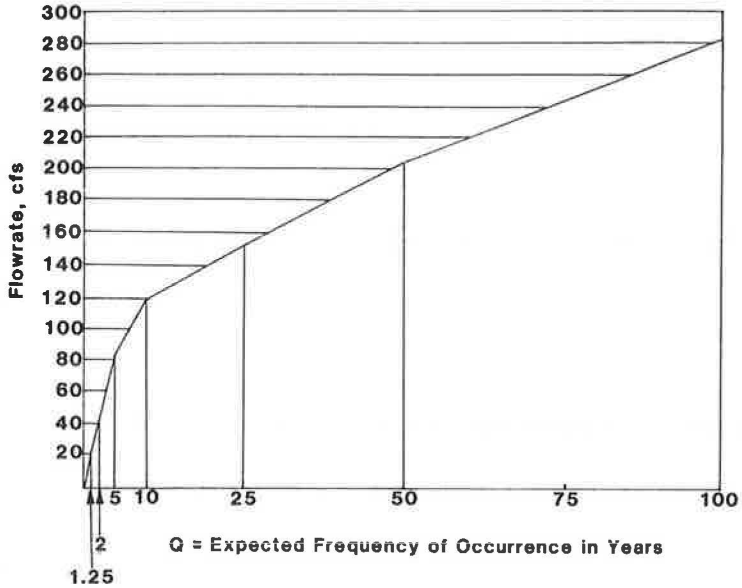

FIGURE 4 Calculated magnitude and frequency of peak discharge.

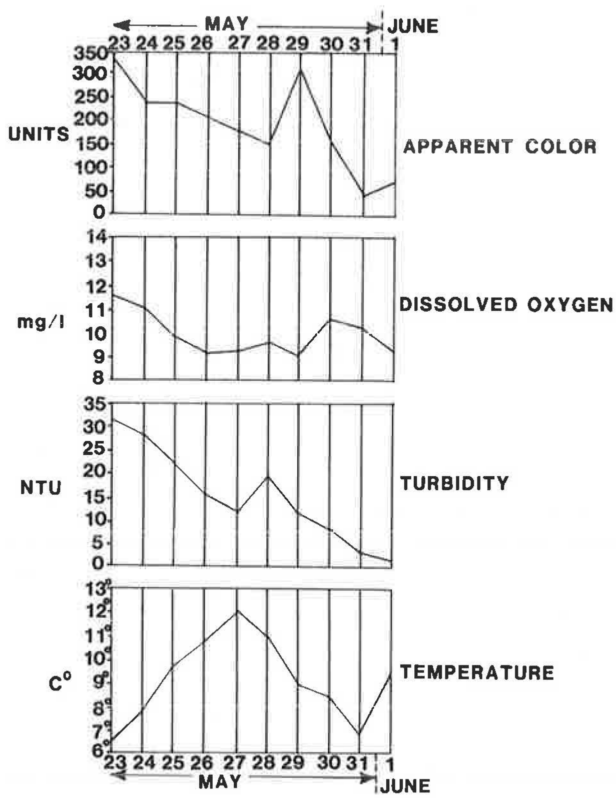

FIGURE 5 Daily water quality parameters.

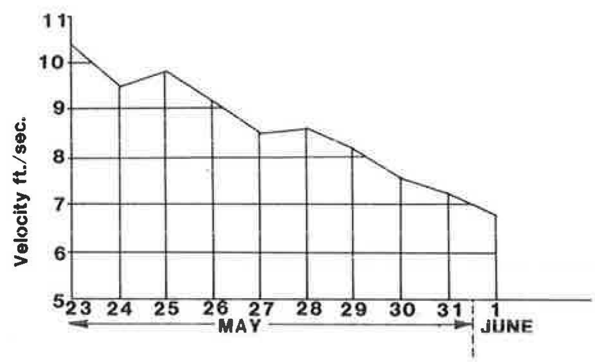

FIGURE 6 Daily outlet velocities.

TABLE 2 Time Durations of Fish Swimming Through Culvert

Tag Color	Number Timed	Mean Time (min)	Range (min)
Yellow	4	20.5	11.9-27.7
Blue	3	19.9	11.5-27.5
Orange	11	28.8	10.75-43.03

smaller fish took 28.8 min. The time range for fish to successfully negotiate the culvert ranged from 10.8 to 43.0 min.

The creel census was performed from May 23 to 29 (Table 3). On several occasions anglers continued fishing in the scour pool late in the evening (beyond midnight) after the investigative team left the project site. Therefore the total number of fish removed from the pool is estimated to be 10 percent more than what is given in Table 3, or approximately 2,600 fish. About 4,180 fish were hooked and landed; some 1,580 were released. Rough handling of fish was observed on numerous occasions. By May 26, most fish larger than 8 in. were dropping eggs or milt when they were lifted from the water by anglers.

Forty-four states and all Canadian provinces responded to the letter of inquiry for fish passage information. Twenty states reported that they usually had no problems with fish passage through highway culverts. Eighteen highway departments reported having a good working relationship with resource agencies when addressing fish passage problems. These 18 departments commonly suggested that (a) early coordination should occur between highway and resource agencies during the design phase, (b) culvert inverts should be depressed approximately 1 to 2 ft below the natural streambed, (c) culverts having slopes greater than 1 percent should have a baffling

TABLE 3 Creel Census

Date	No. of Anglers[a]	Angler Hours[b]	Fish Caught	Fish Kept	Tagged Fish Caught			Tagged Fish Kept		
					Yellow	Blue	Orange	Yellow	Blue	Orange
5/23/85	12	18	103	95	0	0	0	0	0	0
5/24/85	30	37	225	221	1	6	0	1	6	0
5/25/85	65	92.5	726	557	17	35	0	9	17	0
5/26/85	83	149.5	1,370	711	53	32	6	32	28	2
5/27/85	86	143	1,534	620	11	22	4	10	12	2
5/28/85	6	10	104	33	7	13	3	7	11	2
5/29/85	11	13	118	114	2	3	4	2	2	4
Total	293	463	4,180	2,341	91	111	17	67	76	10

[a]Number of anglers = number of anglers interviewed only.
[b]Anglers hours = number of anglers x hours fished.

system, and (d) the remaining culvert volume should be able to handle approximately a Q_{50} discharge.

Several highway departments have a policy of establishing either a formal or an informal fish passage task force. The teams are composed of personnel from various disciplines, including design and hydraulic engineers, environmental specialists, and personnel from resource agencies.

Early in the development of a project, the highway departments contact pertinent resource agencies to determine (a) whether an important fishery utilizes the stream in question; (b) whether there is currently a fish passage problem; and (c) whether there is sufficient spawning and rearing habitat above the culvert to warrant the costs involved in establishing, maintaining, or reestablishing fish passage. On the basis of these determinations, fish passage either becomes a design criteria for the project or is deleted from further consideration. The final fish passage design is coordinated with the resource agencies and is finally approved by the district hydraulics engineer.

Most culverts are positioned parallel along the natural stream gradient. The culverts are depressed approximately 1 to 2 ft below the streambed to prevent perching and are allowed to fill in naturally. If the culvert's slope is greater than 1 percent, either riprap or a baffling system is employed. Baffling consists of a simple concrete weir, removable plates on hangers for simplified maintenance operations, or a variety of complex channeling techniques. Regardless of which system is used, the culvert is usually somewhat oversized to retain its hydraulic capacity for a Q_{50} discharge.

Two state resource agencies reported that they request highway departments to create blocks to fish migration. This is done to prevent the destruction of prime upstream fisheries from the invasion of undesirable fish species (i.e., carp, lamprey, etc.).

DISCUSSION OF RESULTS

Comparison of ADF&G's criteria for a 110-ft culvert (maximum outlet velocity = 1.8 fps) with the observed outlet velocity necessary to pass 78 percent of all fish (7.3 fps) results in a large discrepancy. However, there may be several possible reasons why fish were able to negotiate such a high velocity.

ADF&G fish passage criteria has fixed, maximum values for average cross-sectional outlet velocities for given culvert lengths. The study team observed the fish swimming very close to the culvert bottom and not utilizing the entire water column. Morsell et al. (4) developed a hydrologic model that describes the velocity of a zone close to the culvert bottom, which is called V-occupied. In general, V-occupied equals 0.625 of the average cross-sectional velocity. If this model is valid, then when the average cross-sectional velocity was 7.3 fps, the V-occupied would have been about 4.6 fps. The extrapolated maximum outlet velocities for the ADF&G criteria were generated from studies of Arctic grayling swimming through 2-ft diameter culverts. These smaller pipes possess a much smaller wetted perimeter than the Poplar Grove Creek culvert and thus would generate a smaller V-occupied zone that the fish may not have been able to utilize.

Temperature and spawning motivation may have influenced the fishes' swimming ability. MacPhee and Watts (1) noted that during warmer temperatures and during the upstream spawning runs, grayling were able to swim longer and negotiate higher velocities. ADF&G criteria are based on passing 75 percent of 9.5-in. fish at 2.8°C but does not consider spawning motivation. The fish studied passed through the culvert at about 7.7°C and were migrating upstream to spawn.

The long transient times exhibited by the tagged fish swimming through the culvert suggest that resting areas were available along the bottom. However, this appears unlikely because so much water was flowing through the pipe (64 cfs) when 78 percent of the fish passed. Upstream flow conditions indicated a hydraulic jump near the culvert inlet that would have resulted in an elevated velocity for a short section of the pipe. Further, the center section of the culvert was constricted (Figure 2), which, under selected flow conditions, caused surcharging in the pipe and slower velocities within the constricted section of the culvert. This indicates nonuniform flow conditions in the pipe (constant discharge but varying velocities). It is apparent that the fish were swimming at the extreme limits of their swimming abilities with a slow, net forward speed but with a darting action as they encountered variations in velocities through the pipe.

The final question to be addressed is whether the existing Poplar Grove Creek culvert is inadequate for fish passage. Based on the ADF&G's specification that 75 percent of 9.5-in. fish pass at a $Q_{2.33}$ discharge, then the Poplar Grove Creek culvert is acceptable because 78 percent of the fish population passed through it at approximately 65 cfs, which is about a $Q_{3.3}$ discharge. However, the existing culvert has structural flaws that can only be corrected by replacing it with a new pipe and properly positioning the culvert along the streambed.

During the 8 days that the fish were downstream of the culvert, about 50 percent of the spawning population was removed by sport fishermen. Of the remainder, almost all had been hooked at least once. Because of this, it is recommended that ADF&G consider emergency closures to sport fishing in areas such as Poplar Grove Creek during unusually high flow.

Dryden and Stein (5) suggest that upstream migrating fish should not be held below a culvert for more than 3 days. However, this project did not entirely support this conclusion. The fish studied appeared viable and energetic for the entire 8 days of delay despite the rough handling they endured from sport fishermen. The effects on spawning are unknown.

The study techniques tentatively appear to be simple and effective for analyzing the ability of a particular drainage structure to pass fish. However, two changes are recommended if this procedure is used in the future. First, a smaller, slimmer tag should be used to mark fish that are less than 6 in. Second, during high turbid flows, a small, portable side-scanning sonar counter should be used at the culvert inlet to augment the use of flashboards to count fish and confirm passage.

The highway crossing at Poplar Grove Creek is scheduled to be realigned approximately 100 ft upstream during the 1986 construction season. To meet ADF&G fish passage criteria, a 50-ft long, 10-ft diameter reinforced culvert with reinforced headwalls has been designed. The anticipated cost for this structure is approximately $160,000 (DOT&PF 1986 estimated cost). An 80-ft long, 5-ft diameter culvert similar to the original crossing would cost about $8,000. Such examples suggest the need for ongoing coordination between transportation and fisheries agencies. Obviously, this is a case in which better technical data on the relationship between the behavior of the "design" fish species and the hydraulic operation of highway structures can produce significant cost savings.

Fish passage criteria and techniques that will be cost effective and protect the fisheries resources are in the developmental stages in the state of Alaska. Alaska can learn from other states how they address fish passage issues. The underlying foundation for any criterion is adequate communication between fishery biologists and engineers. Alaska has recently developed a Fish Passage Task Force that is composed of representatives from ADF&G and DOT&PF. Its primary purpose is to bridge the communication gap between the two agencies and to begin working together to solve the problems of fish passage.

SUMMARY AND CONCLUSIONS

Experimental techniques were used to observe fish passage through a highway culvert. Although there were some difficulties with the visual technique, it provided a cost-effective method that did not require sophisticated, expensive monitoring equipment. Observations were hampered by unusually high flows. The population of upstream migrants appeared higher than in previous years.

Some Arctic grayling were able to negotiate a 110-ft long, 5-ft diameter culvert when flows exceeded 9.0 fps. A large portion of the population was unable to pass the culvert during these conditions, and because of this, became highly vulnerable to sport fishing. Most of the remaining fish were able to pass through the drainage structure when the velocity decreased to about 7.0 fps. Some disagreements exist between the study investigators and some individuals of ADF&G about the definition of an attempt and the definition of a failure of a fish in the culvert. ADF&G believes that fish residing in the scour pool should have been included in determining the percent of fish passing through the culvert. An accurate count of fish in the scour pool was not possible because the investigative team was not permitted to recapture fish in the pool.

The experimental procedures used need further evaluation on other streams, culverts, and fish species. The data gathered by this study suggest that the existing ADF&G fish passage criteria may be restrictive and follow-up studies are recommended. Additional studies may provide information leading to criteria that allow for more conservative pipe sizing and cost-effective use of public funds while providing a high degree of protection to fish resources. One final area of study needing a great deal of attention are design criteria at low-flow conditions that might create stream migration blockage.

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